Aggregated Exposure Estimates for Fine Particulate Matter from Indoor and Outdoor Sources - and beyond -

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The Problem with $\text{PM}_{2.5}$

- Guidance lacking for particulate matter (PM) characterization factors in LCIA

Approach to the Problem

- Global initiative for $\text{PM}_{2.5}$ exposure/impacts framework
- Indoor, urban, and rural exposures
  - Exposures to outdoor sources
  - Exposures to indoor sources
- Non-linear exposure-response
- Matrix framework approach

- Case study on rice system results
- Continuing work and next steps
Overall Framework: Impact Pathway

- PM$_{2.5}$ mass as indicator for outdoor and indoor sources
- Exposure metric: intake fraction (start from Humbert et al. 2011)
- Summary health impacts metric: DALY (start from GBD2010/13)

Fantke et al. 2015, JLCA 20: 276-288
The Intake Fraction (iF)

\[ iF = \frac{\text{Population Intake}}{\text{Total Emissions}} = \frac{P \cdot C_i \cdot In_i}{E} \]

- \( C_i \) : Concentration [g/m\(^3\)]
- \( In_i \) : Intake rate [m\(^3\)/person/d], for example breathing rate
- \( P \) : Population [persons]
- \( E \) : Emission rate [g/d]

Bennett et al. 2002, ES&T 36: 207A-211A
Archetypes Matrix Framework

Scenario/geographical archetypes → unknown source: emission-weighted iF

Fantke et al. 2017, ES&T 51: 9089-9100
Archetypes Aggregation Structure

Level 0 -- Default generic iF archetypes (global average)
- Outdoor & indoor
  - Outdoor: urban & rural areas
  - Indoor: residential & occupational settings

Level 1 -- Semi-generic iF archetypes
- Outdoor urban: city size classes (proxy: linear population density)
- Outdoor rural: parameterized geographical regions
- Indoor: ventilation & occupancy & recirculation/filtering classes

Level 2 -- Maximum disaggregated set of iF archetypes
- Outdoor: 3646 specific cities (>100,000 inhabitants in 2000)
- Indoor: specific residential and occupational building types (based on Hodas et al. 2016, Indoor Air)

Fantke et al. 2017, ES&T 51: 9089-9100
Archetypes Uncertainty

Level 0 – Default CF – Single Value *(with distribution)*

Level 1 -- Semi-Generic CFs -- 3 Archetypes *(urban, rural, remote)* *(with distributions)*

Level 2 – City-specific CFs *(with distributions)*

Archetypes Input Urban Areas
Exposure results (LPD vs. POP)

\[ iF_{o,u} = 10^{1.84} \times DR^{-0.876} \times 10^{1.1016\alpha_x} \times POP^{1.1016\beta - 0.1016} \]

Fantke et al. 2017, ES&T 51: 9089-9100
Exposure results (iF distribution)

Fantke et al. 2017, ES&T 51: 9089-9100
Non-linear Exposure-Response

Apte et al. 2015, ES&T 49: 8057-8066
LCA Application: Rice Case Study

- We have selected rice production and consumption as overarching case study

Frischknecht et al. 2016, JLCA 21: 429-442
Rice Case: PM$_{2.5}$ Emissions

Emitted mass [kg] of fine particulate matter (PM$_{2.5}$), and precursors to secondary particles, i.e. SO$_2$, NH$_3$, and NO$_X$, per kilogram of cooked rice in the three scenarios.

Frischknecht et al. 2016, JLCA 21: 429-442
Rice Case: $\text{PM}_{2.5}$ Intake Fractions

![Graph showing intake fractions for different emission compartments: indoor low, indoor high, outdoor urban, outdoor rural. The graph compares fractions for PM$_{2.5}$, NH$_3$, NOX, and SO$_2$.](image-url)
Rice Case: \(\text{PM}_{2.5}\) Health Impacts

Combining intake fractions and exposure-response

Disability-adjusted life years taking (a) the marginal slope at the working point, and (b) the average from the working point to the theoretical minimum-risk per kilogram of cooked rice (DALY) and percent contribution of total secondary \(\text{PM}_{2.5}\) precursor emissions (%) in the three scenarios

Frischknecht et al. 2016, JLCA 21: 429-442
PM$_{2.5}$ Future Model Refinement

- Finalizing exposure-response (ERF) part
- Secondary PM$_{2.5}$ formation indoors and outdoors
  - Equations, models, data under internal review
- Regionalized effect scenarios
  - ERF data for several archetypes ready for implementation
  - Review of and comparison with spatial models
- Publication of ERF model and final LCIA recommendations
Summary of Recommendations

1. Use **archetypes** with different aggregation levels
   - Generic (in/out) | region/city-stack (out) | building type (in)
   - Regions/building types: $f$(most influential parameters)
   - Captures variability **better than current spatial models**!

2. Use **matrix-based** exposure & impact framework

3. Include **indoor & outdoor** sources

4. Include **primary PM$_{2.5}$** (done) & **secondary PM$_{2.5}$** (in progress)

5. Consistent connection of **exposure ↔ ERF**
   - Use GBD ERF for all sources
   - For outdoor, start from $C_{\text{outdoor}}$ for ERF working point
   - For indoor, start from $C_{\text{indoor}}$ for ERF working point (high-end of the ERF curve)

Thank you!

Acknowledgements
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Further reading

Initial guidance on PM2.5: Fantke et al. 2015, JLCA 20: 276-288
Intake fraction modeling framework: Fantke et al. 2017, ES&T 51: 9089-9100
PM2.5 exposure-repsonse: Apte et al. 2015, ES&T 49: 8057-8066
Indoor intake fraction aspects: Hodas et al. 2016, Indoor Air 26: 836-856

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